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Assessing the Impact of Degree Day Base Temperatures on The Development of an Energy Index to Measure Energy Reduction

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Abstract: Refurbishment projects must be monitored before and after technology or behavior changes implementations to be able to assess their effectiveness and to drive conclusions on their applicability. An Energy Index approach has been previously developed and at its foundation, is the implication of base temperature selection on Degree Day for assessing energy reduction. The base temperature used to calculate Degree Days in the UK is 15.5 degrees.

The aim of this study was to assess the impact of Degree Day base temperatures on the development of an Energy Index by means of correlation between energy consumption and Degree Days.

The methodology was based on a low budget energy management strategy, in which the following information was collected: meter readings, internal temperature and outdoor conditions by means of degree-days. The methodology was employed in thirteen flats, with a control group of six flats having electric storage heaters and a further seven flats retrofitted with heat pumps. The flats were retrofitted with heat pumps; meter readings were collected around monthly intervals, while internal temperature was collected at 20 minutes intervals. Energy consumption was correlated to Degree Days based on 15.5 degrees and then compared to the correlation when the base temperature for Degree Days matches the internal flat temperature.

The results show that by matching the base temperature to internal flat temperature, the average correlation improves from 0.55 to 0.76 and the average standard deviation improves from 0.36 to 0.19, meaning that the spread of results is reduced and a better evaluation of refurbishment technology or behavior changes can be achieved. The control group, with electric heater storages, experiences the greater correlation and standard deviation improvements.

Matching the Degree Day base temperature to the internal temperature allows a more realistic accountability for the energy consumption to assess refurbishments by the Energy Index.

Keywords: Degree Day, Base temperature, Energy Consumption, Energy Reduction

Introduction

If the true benefits of refurbishment implementation need to be understood, then refurbishment projects must be monitored before and after technology or behavior changes implementations to be able to assess their effectiveness and to drive conclusions on their applicability. An Energy Index approach has been previously developed (Jimenez-Bescos, 2015) and at its foundation, is the implication of base temperature selection on Degree Day for assessing energy reduction.

Degree Days have been used for some times and its calculation well explained (CIBSE, 2006 and Krarti, 2012). Although originally used in agriculture, the use of Degree Days are nowadays used as a forecasting tool for energy demand (Hong, 2013). Degree Days are widely used to forecast the energy demand of a house in the future or for normalising energy meter readings to allow for comparisons between different years. For example, the energy use during the month of February will be different each year in accordance to a soft winter or a hard winter. Degree days records the severity of softness of the weather and allows us to compare different years after normalisation. Furthermore, Degree Days can be used to estimate the energy demand of regions or communities (Mitchell, 1987)

A key aspect for the calculation and use of Degree Days is the base temperature or balance point temperature (Layberry, 2008). According to Layberry (2009), plotting energy use versus Degree Day will generate a straight line when the base temperature is correct.

Due to the importance of the base temperature to calculate the correct Degree Days, methodologies have been developed to calculate the base temperature, as presented by Day et al (2003). Some of these methodologies relay on the calculation of the building energy signature, as presented by Krese et al (2012), which involves plotting daily electrical consumption versus mean daily temperature. As subjected by the author, the main disadvantage is the requirement of high resolution consumption data.

The base temperature for Degree Days in the UK is taken as 15.5 degrees, although the true base temperature can oscillate (Walsh, 1993). Chosen the wrong base temperature will introduce an error in the Degree Day calculation (Woods and Fuller, 2014).

The aim of this study was to assess the impact of Degree Day base temperatures on the development of an Energy Index by means of correlation between energy consumption and Degree Days.

Research Methods

The methodology was based on a low budget energy management strategy, in which the following information was collected: meter readings, internal temperature and outdoor conditions by means of Degree Days as presented in Jimenez-Bescos (2015). The methodology was employed in thirteen flats in total, containing a control group of six flats, in building one, having electric storage heaters and a further seven flats, in building two and three, which were retrofitted with air source heat pumps. A control group was used due to unavailability of data during the pre-retrofit period due to data lost in the monitoring process. This is one of the main challenges dealing with monitoring as presented by (Jimenez-Bescos, 2016). The thermal envelope of the three buildings was outside the scope of the project but data collection visit highlighted that a fabric first approach should have been taken prior to retrofitting air source heat pumps. The buildings fabric, at least walls and roof insulation, would have benefit from improvement and airtightness levels were quite low producing a very leaky envelope, which was less than ideal for an air source heat pump installation.

For all the flats, meter readings were collected at roughly monthly intervals, while internal temperature was collected at 20 minutes intervals. The internal temperature was average to a daily value to be used as base temperature to calculate Degree Days. Furthermore, the internal temperature was average across the dates between meter readings. Energy consumption was correlated to Degree Days based on two different approaches:

- Following a base temperature of 15.5 degree centigrade.
- A base temperature for Degree Days matching the internal flat temperature as a daily average.

The coefficient of determination, R^2, was used to assess the correlation between energy consumption and Degree Days. The coefficient of determination expresses how much the dependency of the dependent variable, energy consumption, can be explained by the independent variable, Degree Days (Bryman, 2004). The coefficient of determination will vary between a value of 0 and 1, the closer to 1 the stronger the correlation between the variables. A value closer to 0 indicates no relationship of any significance between variables. It must be noted that a strong correlation does no imply cause and effect (Collis and Hussey, 2003).

The Degree days were calculated on a daily basis in accordance to the two base temperature approaches, 15.5 degree centigrade and internal temperature, and added together following the interval of meter reading.

Results

The results presented in Table 1 and Figure 1 show that, by matching the base temperature to internal flat temperature, the average correlation for all the thirteen flats improved from 0.55 to 0.76 and the average standard deviation improved from 0.36 to 0.19, meaning that the spread of results is reduced and a better evaluation of refurbishment technology or behavior changes can be achieved. The level of correlation was improved from slightly statistical significant to a good correlation between energy consumption and Degree Days calculated by matching the base temperature to the internal temperature of the flats. The most important detail regarding the improved correlation is not related to increasing the value and getting closer to 1, but to be able to capture and understand that in many cases such as flats 3 and 11, the use of energy can be understood and compare to the other flats. It must be noted that in some cases, for example flats 4 and 10, the correlation value is reduced but still keeping reasonable levels of strong correlation.

Table 1. Coefficient of Determination (R^2) for the thirteen flats for base temperatures of 15.5 degrees and internal temperature.

R2	15.5 Degree	Int Temp
Flat 1	0.8535	0.8368
Flat 2	0.4826	0.9273
Flat 3	0.0003	0.7753
Flat 4	0.9905	0.8842
Flat 5	0.6706	0.5502
Flat 6	0.1186	0.3886
Flat 7	0.7058	0.9222
Flat 8	0.6338	0.9342
Flat 9	0.6212	0.6821
Flat 10	0.9497	0.8126
Flat 11	0.053	0.4722
Flat 12	0.9651	0.9655
Flat 13	0.1868	0.7944
Average	0.5563	0.7650
SD	0.3583	0.1877

Table 2 shows the coefficient of determination, R2, split between electric storage heaters (control group) and air source heat pump. The control group with electric heaters was showing a lower correlation average at roughly 0.5, while the group with air source heat pumps presented a correlation of about 0.6 for a base temperature of 15.5 degree centigrade. It must be noted that by using the internal temperature as base temperature for the Degree Days calculations, both groups, electric storage heaters and air source heat pump users, achieve a very similar correlation average of 0.76.

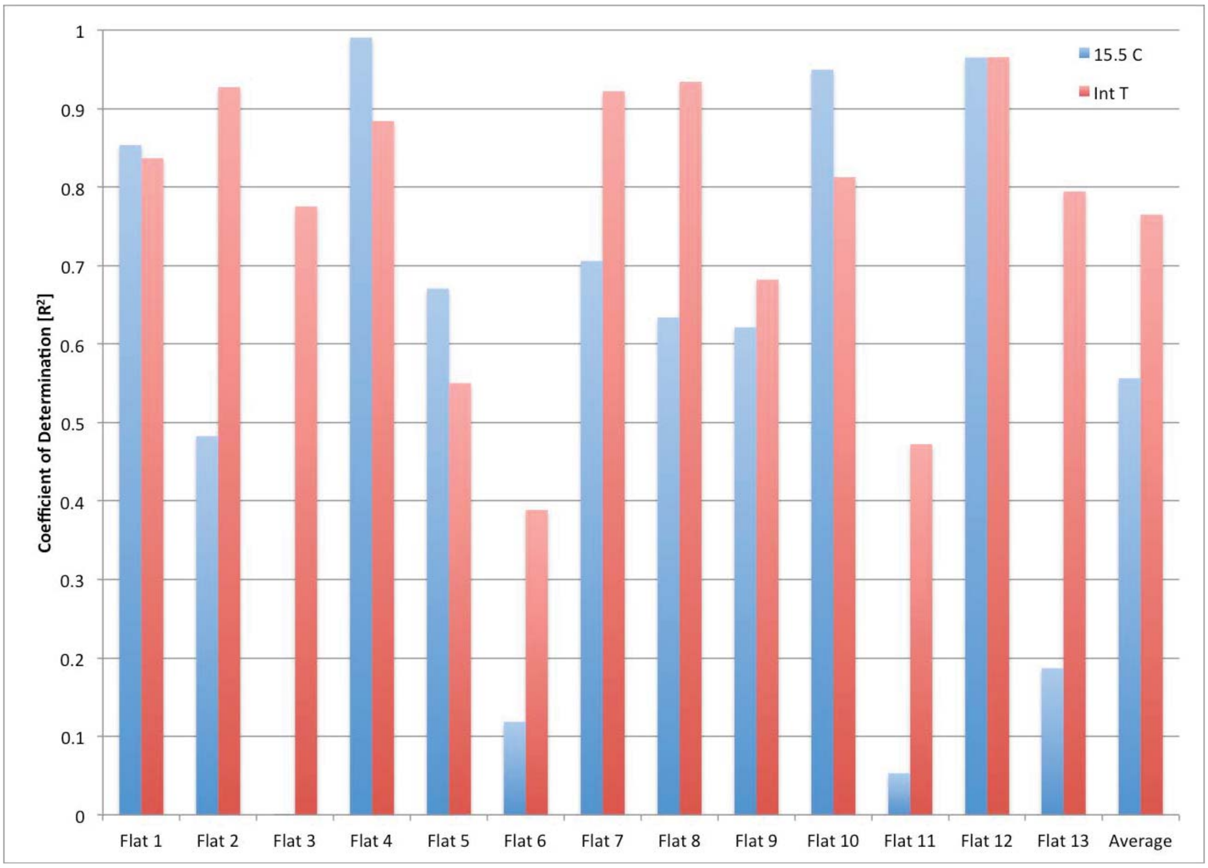

Figure 1. Coefficient of Determination (R^2) for the thirteen flats for base temperatures of 15.5 degrees and internal temperature.

Table 2. Coefficient of Determination (R^2) in accordance to heating method.

Electric Storage Heaters			**Air Source Heat Pump**		
R2	**15.5 Degree**	**Int Temp**	R2	**15.5 Degree**	**Int Temp**
Flat 7	0.7058	0.9222	**Flat 1**	0.8535	0.8368
Flat 8	0.6338	0.9342	**Flat 2**	0.4826	0.9273
Flat 9	0.6212	0.6821	**Flat 4**	0.9905	0.8842
Flat 10	0.9497	0.8126	**Flat 5**	0.6706	0.5502
Flat 3	0.0003	0.7753	**Flat 6**	0.1186	0.3886
Flat 11	0.053	0.4722	**Flat 12**	0.9651	0.9655
			Flat 13	0.1868	0.7944
Average	0.4940	0.7664	**Average**	0.6097	0.7639
SD	0.3812	0.1722	**SD**	0.3584	0.2139

Discussion

The results presented in Table 1 and 2, as well as Figure 1, support the importance of the base temperature to calculate the correct Degree Day, as stated by Layberry (2008). Suggesting that the used of internal temperature as a base temperature will provide a closer match to an straight line when plotting energy versus Degree Days, as suggested by Layberry (2009), by having a closer to 1 value for the coefficient of determination (R^2) and showing a stronger correlation between energy consumption and Degree Days. The improvement is well appreciated in flats 3 and 11, where it can be attributed to the difference between internal temperature of the flat and the standard base temperature of 15.5 degrees centigrade.

While some of the methodologies to calculate the base temperature, such as the building energy signature (Krese et al, 2012), will have some issues related to the resolution of the data collected, the use of the internal temperature will be relatively easy to monitoring and store by means of a data logger. In the awakening of the Internet of Things (ioT) and a growing number of sensors and data loggers around the house, providing a means to measure and store internal temperature is quite straightforward and will results in a more accurate calculation of the Degree Days by selecting the correct base temperature and avoiding errors (Woods and Fuller, 2014).

Comparing the correlations by using the stipulated base temperature of 15.5 degree centigrade or the internal temperature as base temperature, it can be observed that a better match between the energy consumption and Degree Days can be achievable and as a result, better energy demand projections can be estimated from these correlations.

The findings in this paper support the use of the internal temperature of properties as base temperature to calculate more accurate Degree Days. This methodology has been developed as an energy index (Jimenez-Bescos, 2015) to provide a more accurate approach to compare heating energy performance of different properties for non professional people and to make initial judgements on performance by technology improvements and/or user behaviour measures.

The energy index methodology has been successfully applied to a retrofit case in the United Kingdom, in which air source heat pump combined with user behaviour measures were deploying to reduce energy use and carbon emissions (Jansson-Boyd, 2016). By using internal temperatures as base temperatures for the Degree Days calculation a more accurate energy use profile was developed to evaluate the benefits of energy efficiency measures.

Conclusion

Matching the Degree Day base temperature to the internal temperature allows a more realistic accountability for the energy consumption to assess refurbishments by the Energy Index. Providing support for the use of an energy index methodology to normalized the energy use consumption data for easy comparison across properties, seasons and locations.

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